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Key Words: LAPD, ODH, PC4, PC3

Abstract Summary:

This is the ODH assessment for the LAPD argon tank and associated equipment.

Applicable Codes:

1. *Fermilab Oxygen Deficiency Hazards (ODH), FESHM Chapter 5064, June, 2012.*

FERMI NATIONAL ACCELERATOR LABORATORY

LAPD ODH ASSESSMENT

Mark Adamowski

November 13, 2012

I. INTRODUCTION

This ODH risk assessment is for the Liquid Argon Purification Demonstration (LAPD) facility located in PC4. A Fatality Rate is computed to determine the ODH Classification. The ODH risk severity is computed from cryogen release probabilities and the associated impact on PC4's oxygen content. PC4 is located at FERMI and FESHM 5064 fatality factors are used. These fatality factors combined with the cryogen release potentials are used to express the ODH risk as a total fatality rate with its associated ODH Class.

The LAPD project has an argon storage tank and argon purification system in PC4 to produce ultrapure Argon. A pumped circulation and filtration system is used to reduce impurities in the Argon. Liquid nitrogen is used as a coolant to remove heat absorbed by the argon system by condensing argon gas. Vents are purged with argon gas from argon dewars.

PC4 is connected the PC3 tunnel section. PC4 is the emergency exit route from PC3. The ODH risk for PC3 from PC4 is also assessed.

II. SIZES AND VOLUMES

The PC4 building space is comprised of a central enclosure and a beam enclosure. For the purposes of this analysis only the central enclosure is being counted. Only the people space of floor to 6 foot is being counted since heavier than air gases are involved. The resulting volume for analysis is 60,249 cubic feet. Room dimensions[1] and calculation details are in the appendix A.

PC3 is a tunnel section connected at the south end of PC4. Tunnel dimensions and PC3 related calculations are in Appendix B.

Liquid argon will be stored in PC4, in the LAPD tank. This tank will hold 6,000 gallons (663,000 SCF) of liquid argon, when full. Liquid argon to fill the tank will be supplied from an argon trailer, located outside. Argon will be also be used as purge gas. The argon for purging will be supplied from argon Dewars, located outside.

Liquid nitrogen will provide cooling for the LAPD tank. The liquid nitrogen will be supplied from a liquid nitrogen trailer, located outside. The trailer assigned to LAPD is trailer #22 which can hold 4,000 gallons (364,800 SCF) of liquid nitrogen.

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[1] Drawing 8-4-4-PS-2, REV A/B, Jan 4, 1974, Titled: Proton Laboratory Phase G

Filter regeneration will use combination gases, argon/hydrogen gas and nitrogen gas. The combination gases and argon/ hydrogen gas will be supplied from gas bottles stored outside. The nitrogen gas will be supplied from the same outside, liquid nitrogen trailer supplying the LAPD cooling. The liquid nitrogen will pass through a vaporizer, located outside, before entering PC4.

III. VENTILATION SYSTEMS

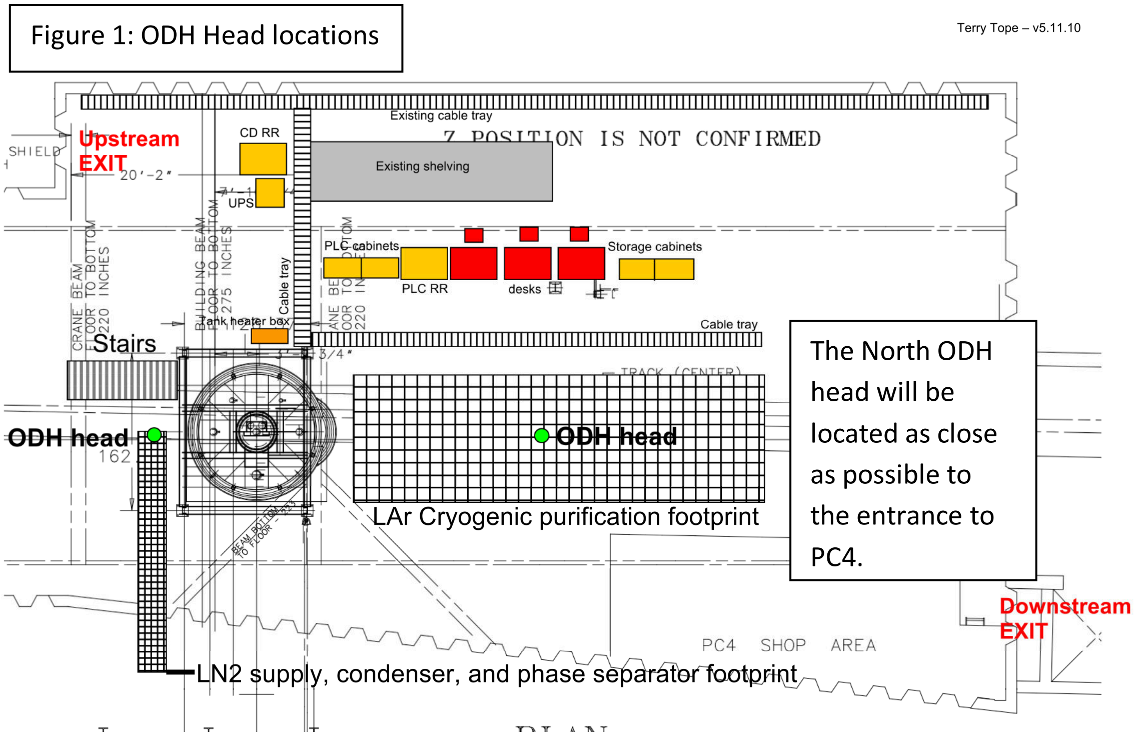
PC4 has existing basic ventilation. All the existing ventilation intakes and exhausts are located near the ceiling and will have little effect on risks from heavier than air gases. For this reason, the existing ventilation is not counted in this ODH analysis.

PC3 had ventilation that is no longer operational and not easily repaired. A large ventilation duct is present near the entrance to PC3. A fan was added to this duct to draw in fresh air and ventilate PC3. FESS changed the door to PC3 into a solid door. With this change, the ventilation air from PC3 exhausts into PC4. The installed fan has sufficient static pressure to push air into PC4 even if PC4 is ODH compromised. A 16 inch axial fan will be used to provide a minimum of 500 CFM at 0.125" static pressure. This provides 1.5 air exchanges per hour. The cases that were evaluated in selecting this fan are detailed in Appendix B.

IV. ODH DETECTORS

There will be two ODH detectors in PC4. These detectors are near the LAPD tank and the filtration loop. The detectors will be located at ground level. These detectors are expected to detect an Argon or Nitrogen leak from the LAPD system. The detector locations are indicated in Figure 1.

Figure 1: ODH Head locations



The North ODH head will be located as close as possible to the entrance to PC4.

V. LAPD ODH EXHAUST SYSTEM

When an ODH condition is signaled by any of the ODH detectors the following automated responses occur:

A. Activation of ODH alarm horns and lights

B. Activation of the ODH exhaust blower

A large ODH exhaust blower will be located at floor level in PC4. This blower will draw heavier than air gases from floor level in the vicinity of the LAPD system and exhaust the gases outside. Fresh air is drawn in through existing louvers near the ceiling on the East and West wall.

The ODH exhaust blower has been tested before LAPD work starts. There is sufficient existing building fresh air vent capacity. Additional air intakes are not needed.

During LAPD operation, the ODH exhaust blower will be energized for a short period of time each day to confirm that the blower is operational. Proper operation is confirmed by a flow switch on the blower outlet. All blower failure modes (power, fuse, motor, belt, or mechanical linkage) will be detected as a lack of pressure on the blower outlet. The LAPD PLC will inform the Fermi Facility Information Reporting Utility System (FIRUS) and use its auto dialer to inform LAPD personnel.

VI. SIGNIFICANT SOURCES OF CRYOGENS

The following are the significant sources of cryogens and gases which could produce ODH conditions in PC4 during LAPD work. These are the sources considered in the analysis of component failures or ruptures. The potential leak rates for argon and nitrogen are based on available pressure and leak size. The details can be found in the appendix. There are no cryogens in use or stored in PC3.

LIQUID NITROGEN SUPPLY HEADER

The nitrogen supply header brings liquid nitrogen from the outside trailer. This header is part of the LAPD system and holds a finite nitrogen supply of 4,000 gallons (364,800 SCF).

Trailer Tank Normal Operating Range: 30-40 psig

Trailer Maximum Allowable Working Pressure: 50 psig

LIQUID ARGON SUPPLY HEADER

The argon supply header brings liquid argon from an outside liquid argon trailer during LAPD tank filling. This trailer holds a maximum argon supply of 4,000 gallons (442,000 SCF).

Liquid argon dewars, located outside, will be supplying continuous argon for purge gas after LAPD tank filling is complete. There will be multiple connections available for hooking up liquid argon dewars.

ARGON/HYDROGEN GAS HEADER

A gas header brings a 95% argon/5% hydrogen gas mixture from an outside trailer. This trailer has a finite capacity of 40,000 standard cubic feet of the argon/hydrogen gas mixture.

NITROGEN GAS HEADER

A nitrogen gas header provides nitrogen gas from an outside nitrogen ambient vaporizer. This vaporizer is feed by the same liquid nitrogen trailer gas identified above.

ARGON GAS HEADER

An argon gas header will provide argon gas from outside dewars. This header will operate with a pressure regulator and the individual purge points will be fed by small stainless steel tubing and rotometer.

LAPD TANK

The LAPD tank has a volume of 6,500 gallons. Once filled, the LAPD tank would be kept full for the LAPD work. The liquid argon is pumped from the tank through filtration steps and then back to the tank.

ARGON FILTRATION VESSELS

When the filtration system is operating, the filtration vessels would contain liquid argon. During filtration, a liquid argon pump provides liquid argon, pumped from the LAPD Tank at a maximum of 2900 liters per hour (13 gpm). When not filtering, the filter vessels empty, as the liquid argon boils off. The filtration system argon boil-off gas is condensed and returned to the LAPD Tank.

VII. FAILURES CONTRIBUTING TO ODH

A. Pressure Vessel – Leak and Failure

All of the small vessels, used in the LAPD tank cooling system and in the argon filtration loop are pressure vessels. These vessels are the vacuum jacketed filters, vacuum jacketed pump, argon condenser and nitrogen phase separator.

A conservative catastrophic failure rate[2] of 1.09×10^{-8} per hour is being used. More likely is that a pressure vessel develops a leak. The risk of leak is an order of magnitude greater than the vessel catastrophic failure risk so a rate of 1.09×10^{-7} per hour is being used for the leak risk[3]. The details for these numbers are in the appendix.

[2] Ref. 2

[3] Leak risk based on a combination of ref. 2 and ref. 3 data. See appendix for details.

The release rate from a catastrophic failure is estimated as the flow that can occur through the largest piping port on the vessel. This assumes the failure has totally severed that port.

B. LAPD Tank – Leak and Failure

The LAPD tank is manufactured to API 620, appendix Q standards and has 100% radiography. This reduces its leak and catastrophic failure risks to a level comparable to pressure vessels. The pressure vessel leak and catastrophic failure rates will be used.

For the vessel failure release rate the flow through a 2" schedule 40 port is used because the flow from a severed port below liquid level will exceed the release rate from a severed port in the vapor space because this is a low pressure tank.

C. Piping – Leak and Failure

Piping probabilities for leaks and failure are from FESHM 5064.

D. Flanges and Conflats – Leak and Failure

Probabilities for leaks and failures of flanges are from FESHM 5064.

E. Human Error – Opening Valve

The argon pump loop has several piping connections points for servicing the filters. One of these connection points could be uncapped and operated in error without proper positioning of block valves. A failure rate of 1.25×10^{-5} per hour was estimated for this possibility. Details are contained in the appendix.

F. Relief Valve - Leak and Release

The large LAPD tank relief valve is vented to the outside. The vent piping is handled as piping with leak and failure risks as noted previously.

The small relief valves protecting the filter vessels are assumed to vent inside PC4. One of these relief valves would release if a filter vessel is blocked in by human error. The human failure rate estimated earlier for opening a valve is applied. A filter (22.5 gal) contains insufficient cryogen to exceed a fatality rate= 0 impact on PC4.

The small relief valves on the condenser and phase separator are assumed to vent inside PC4. A liquid full phase separator (29 gal) contains insufficient cryogen to exceed a fatality rate=0 impact on PC4. This is also true for the smaller condenser vessel.

Trapped volume relief valves on the argon and nitrogen piping are also assumed to vent inside PC4. All piping trapped volumes contain insufficient cryogen to exceed a fatality rate=0 impact in PC4. Details are contained in the appendix.

G. PC4 ODH Event – Impacting PC3

An ODH event in PC4 impacts PC3 ODH when the release is greater than the ODH fan can handle or when there is a failure of the ODH fan. A separate column is contained in Table 1 indicating these risks and tabulating the ODH risk.

VIII. ODH CALCULATIONS

Oxygen concentrations are calculated using FESHM, 5064, equation 4 at time equal to infinity.

$$C = 0.21 \cdot \left(1 - \frac{R}{Q}\right)$$

- Q is the rate the ventilation is drawing out the contaminated atmosphere.
- R is the spill rate of the air displacing gas.
- C is the concentration of oxygen assuming perfect mixing.

It is assumed that any leak occurring during blower failure will drive the oxygen concentration to 0%, as time approaches infinity.

The fatality factor is per the graph in figure 1, FESHM 5064. An equation was used to represent the graph in the ODH analysis, detailed in Table 1.

IX. PC4 RECOMMENDATIONS

The total of the fatality risk rate without an ODH exhaust blower is 3.81×10^{-4} per hour which is ODH Class 2. Addition of a 3,000 CFM ODH exhaust blower reduced the fatality risk rate to 6.58×10^{-8} per hour. Addition of the ODH exhaust blower reduces the fatality risk rate from an ODH Class 2 to ODH Class 0.

A 3000 CFM ODH blower is used for LAPD to achieve ODH class 0. The ODH tabulation with the 3000 CFM blower is shown in Table 1.

X. PC3 IMPACT

PC3 is ODH class 0 from a risk standpoint. The exit from PC3 enters an ODH class 0 area.

XI. REFERENCES

1. ***FESHM 5064, June, 2012***
2. ***Guidelines for Process Equipment Reliability Data, CCPS, 1989***
3. ***Risk Analysis for Process Plant, Pipelines and Transport, 1st ed, 1994***

TABLE 1: LAPD Oxygen Deficiency Hazard Analysis

LAPD SPACE (building PC4): 60,249 cu. ft. (based on 6ft height for people space)
ODH Exhaust: 3,000 cu. ft./min PC4 Exhaust Ventilation 0 cu. ft./min
Total Exhaust Affecting ODH 3,000 (vent. + ODH exhaust) PC4 will have two ODH fans, only 1 fan is needed for LAPD rev. 11/09/12
Ventilation Failure Rate: 1.46E-04 /hr (Includes ODH monitoring system failure, see failure rate calculation in appendix)

	Failure Type	# of	Individual Failure Rate (/hr)	SOURCE	Total Failure Rate for Item	Leak rate, into people space (CFM)	C(O2) at infinity	Fatality Factor	PC4 Fatality Rate	ODH CLASS	PC3 Fatality Rate	ODH CLASS	Notes
EQUIPMENT													
LAPD Tank w/ vent.													
TANK	leak	1	1.09E-07	D	1.09E-07	103	20.28%	0.00E+00	0	0	0	0	small leak
TANK	failure	1	1.09E-08	D	1.09E-08	22240	0.00%	1.00E+00	1.09E-08	0	1.09E-08	0	catastrophic failure
conflat	leak	30	4.00E-07	B	1.20E-05	4	20.97%	0.00E+00	0	0	0	0	
conflat	blowout	30	0.00E+00	B	0.00E+00	18	20.87%	0.00E+00	0	0	0	0	
conflat	break	1	1.00E-09	B	1.00E-09	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
side manway	leak	1	4.00E-07	B	4.00E-07	103	20.28%	0.00E+00	0	0	0	0	
top manway	leak	1	4.00E-07	B	4.00E-07	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
LAPD Tank w/o vent.													
TANK	leak	1	1.09E-07	D	1.09E-07	103	0.00%	1.00E+00	1.60E-11	0	1.60E-11	0	
TANK	failure	1	1.09E-08	D	1.09E-08	22240	0.00%	1.00E+00	1.60E-12	0	1.60E-12	0	
conflat	leak	30	4.00E-07	B	1.20E-05	4	0.00%	1.00E+00	1.76E-09	0	1.76E-09	0	
conflat	blowout	30	0.00E+00	B	0.00E+00	18	0.00%	1.00E+00	0	0	0	0	
conflat	break	1	1.00E-09	B	1.00E-09	33	0.00%	1.00E+00	1.46E-13	0	1.46E-13	0	
side manway	break	1	4.00E-07	B	4.00E-07	103	0.00%	1.00E+00	5.86E-11	0	5.86E-11	0	
top manway	break	1	4.00E-07	B	4.00E-07	33	0.00%	1.00E+00	5.86E-11	0	5.86E-11	0	
Condenser w/ vent.													
VESSEL	leak	1	1.09E-07	D	1.09E-07	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up rate
VESSEL	failure	1	1.09E-08	D	1.09E-08	33	20.77%	0.00E+00	0	0	0	0	small LAr inventory / release limited by boil-up from main tank
relief valve - relief event	error	1	1.25E-05	A	1.25E-05	300	18.90%	0.00E+00	0	0	0	0	human error - blocks in cond.
relief valve	leak	1	1.00E-05	A	1.00E-05	0	21.00%	0.00E+00	0	0	0	0	meets API-527, leak<0.001 cfm
Condenser w/o vent.													
VESSEL	leak	1	1.09E-07	D	1.09E-07	33	0.00%	1.00E+00	1.60E-11	0	1.60E-11	0	
VESSEL	failure	1	1.09E-08	D	1.09E-08	33	0.00%	1.00E+00	1.60E-12	0	1.60E-12	0	
relief valve - relief event	error	1	1.25E-05	A	1.25E-05	300	20.00%	0.00E+00	0	0	0	0	
relief valve	leak	1	1.00E-05	A	1.00E-05	0	21.00%	0.00E+00	0	0	0	0	
N2 Phase Sep. w/ vent.													
VESSEL	leak	1	1.09E-07	D	1.09E-07	203	19.58%	0.00E+00	0	0	0	0	small leak
VESSEL	failure	1	1.09E-08	D	1.09E-08	10147	0.00%	1.00E+00	1.09E-08	0	1.09E-08	0	est. equal to LN2 pipe break
relief valve - relief event	error	1	1.25E-05	A	1.25E-05	300	18.90%	0.00E+00	0	0	0	0	human error - blocks in sep.
relief valve	leak	1	1.00E-05	A	1.00E-05	0	21.00%	0.00E+00	0	0	0	0	meets API-527, leak<0.001 cfm
N2 Phase Sep. w/o vent.													
VESSEL	leak	1	1.09E-07	D	1.09E-07	203	0.00%	1.00E+00	1.60E-11	0	1.60E-11	0	
VESSEL	failure	1	1.09E-08	D	1.09E-08	10147	0.00%	1.00E+00	1.60E-12	0	1.60E-12	0	
relief valve - relief event	error	1	1.25E-05	A	1.25E-05	300	20.00%	0.00E+00	0	0	0	0	limited inventory no ODH
relief valve	leak	1	1.00E-05	A	1.00E-05	0	21.00%	0.00E+00	0	0	0	0	
Argon Pump w/ vent.													
VESSEL	leak	1	1.09E-07	D	1.09E-07	287	18.99%	0.00E+00	0	0	0	0	small leak
VESSEL	failure	1	1.09E-08	D	1.09E-08	1703	9.08%	6.13E-01	6.68E-09	0	0	0	limited by max. pump rate
Argon Pump w/o vent.													
VESSEL	leak	1	1.09E-07	D	1.09E-07	287	18.99%	0.00E+00	0	0	0	0	
VESSEL	failure	1	1.09E-08	D	1.09E-08	1703	9.08%	6.13E-01	9.79E-13	0	9.79E-13	0	
Filter Vessels w/ vent.													
VESSEL	leak	2	1.09E-07	D	2.18E-07	287	18.99%	0.00E+00	0	0	0	0	small leak
VESSEL	failure	2	1.09E-08	D	2.18E-08	1703	9.08%	6.13E-01	1.34E-08	0	0	0	limited by max pump rate
VENT VALVE	error	2	1.25E-05	A	2.50E-05	1000	14.00%	1.11E-04	2.76E-09	0	0	0	human error - opens vent valve
relief valve - relief event	error	2	1.25E-05	A	2.50E-05	300	18.90%	0.00E+00	0	0	0	0	human error - blocks in filter
relief valve	leak	2	1.00E-05	A	2.00E-05	0	21.00%	0.00E+00	0	0	0	0	meets API-527, leak<0.001 cfm
Filter Vessels w/o vent.													
VESSEL	leak	2	1.09E-07	D	2.18E-07	287	0.00%	1.00E+00	3.19E-11	0	3.19E-11	0	
VESSEL	failure	2	1.09E-08	D	2.18E-08	1703	0.00%	1.00E+00	3.19E-12	0	3.19E-12	0	
VENT VALVE	error	2	1.25E-05	A	2.50E-05	1000	0.00%	1.00E+00	3.66E-09	0	3.66E-09	0	
relief valve - relief event	error	2	1.25E-05	A	2.50E-05	300	20.00%	0.00E+00	0	0	0	0	limited inventory no ODH
relief valve	leak	2	1.00E-05	A	2.00E-05	0	21.00%	0.00E+00	0	0	0	0	
PIPING													
N2 Supply w/ vent.													
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	203	19.58%	0.00E+00	0	0	0	0	
PIPES < 2"	leak, large	100	0.00E+00	B	0.00E+00	10147	0.00%	1.00E+00	0	0	0	0	
PIPES < 2"	break	100	9.14E-12	B	9.14E-10	10180	0.00%	1.00E+00	9.14E-10	0	9.139E-10	0	
Flanges	leak	4	4.00E-07	B	1.60E-06	203	19.58%	0.00E+00	0	0	0	0	
Flanges	blowout	4	0.00E+00	B	0.00E+00	967	14.23%	7.37E-05	0	0	0	0	
Flanges	break	4	1.00E-09	B	4.00E-09	6445	0.00%	1.00E+00	4.00E-09	0	3.999E-09	0	
VALVE	leak	4	1.00E-08	A	4.00E-08	203	19.58%	0.00E+00	0	0	0	0	
Trapped V reliefs	leak	12	1.00E-05	A	1.20E-04	0	21.00%	0.00E+00	0	0	0	0	circleseal leak=0 below reseal P
N2 Supply w/o vent.													
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	203	0.00%	1.00E+00	4.47E-12	0	4.47E-12	0	
PIPES < 2"	leak, large	100	0.00E+00	B	0.00E+00	10147	0.00%	1.00E+00	0	0	0	0	
PIPES < 2"	break	100	9.14E-12	B	9.14E-10	10180	0.00%	1.00E+00	1.34E-13	0	1.34E-13	0	
Flanges	leak	4	4.00E-07	B	1.60E-06	203	0.00%	1.00E+00	2.34E-10	0	2.34E-10	0	
Flanges	blowout	4	0.00E+00	B	0.00E+00	967	0.00%	1.00E+00	0	0	0	0	
Flanges	break	4	1.00E-09	B	4.00E-09	6445	0.00%	1.00E+00	5.86E-13	0	5.86E-13	0	
VALVE	leak	4	1.00E-08	B	4.00E-08	203	0.00%	1.00E+00	5.86E-12	0	5.86E-12	0	
Trapped V reliefs	leak	12	1.00E-05	B	1.20E-04	0	21.00%	0.00E+00	0	0	0	0	

	Failure Type	# of	Individual Failure Rate (/hr)	SOURCE	Total Failure Rate for Item	Leak rate, into people space (CFM)	C(O2) at infinity	Fatality Factor	PC4 Fatality Rate	ODH CLASS	PC3 Fatality Rate	ODH CLASS	Notes
N2 vent gas w/ vent.													
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	18	20.87%	0.00E+00	0	0	0	0	
PIPES < 2"	leak, large	100	0.00E+00	B	0.00E+00	717	15.98%	3.44E-06	0	0	0	0	
PIPES < 2"	break	100	9.14E-12	B	9.14E-10	3382	0.00%	1.00E+00	9.14E-10	0	9.139E-10	0	
Flanges	leak	1	4.00E-07	B	4.00E-07	18	20.87%	0.00E+00	0	0	0	0	
Flanges	blowout	1	0.00E+00	B	0.00E+00	181	19.73%	0.00E+00	0	0	0	0	
Flanges	break	1	1.00E-09	B	1.00E-09	1210	12.53%	1.45E-03	1.45E-12	0	0	0	
VALVE	leak	1	1.00E-08	A	1.00E-08	18	20.87%	0.00E+00	0	0	0	0	small leak
N2 vent gas w/o vent.													
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	18	0.00%	1.00E+00	4.47E-12	0	4.47E-12	0	
PIPES < 2"	leak, large	100	0.00E+00	B	0.00E+00	717	0.00%	1.00E+00	0	0	0	0	
PIPES < 2"	break	100	9.14E-12	B	9.14E-10	3382	0.00%	1.00E+00	1.34E-13	0	1.34E-13	0	
Flanges	leak	1	4.00E-07	B	4.00E-07	18	0.00%	1.00E+00	5.86E-11	0	5.86E-11	0	
Flanges	blowout	1	0.00E+00	B	0.00E+00	181	0.00%	1.00E+00	0	0	0	0	
Flanges	break	1	1.00E-09	B	1.00E-09	1210	0.00%	1.00E+00	1.46E-13	0	1.46E-13	0	
VALVE	leak	1	1.00E-08	A	1.00E-08	18	0.00%	1.00E+00	1.46E-12	0	1.46E-12	0	
Argon Loop w/ vent.													
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	287	18.99%	0.00E+00	0	0	0	0	
PIPES < 2"	leak, large	100	0.00E+00	B	0.00E+00	1703	9.08%	6.13E-01	0	0	0	0	limited by max pump
PIPES < 2"	break	100	9.14E-12	B	9.14E-10	1703	9.08%	6.13E-01	5.61E-10	0	0	0	limited by max pump
Flanges	leak	12	4.00E-07	B	4.80E-06	287	18.99%	0.00E+00	0	0	0	0	
Flanges	blowout	12	0.00E+00	B	0.00E+00	1703	9.08%	6.13E-01	0	0	0	0	limited by max pump
Flanges	break	12	1.00E-09	B	1.20E-08	1703	9.08%	6.13E-01	7.36E-09	0	0	0	limited by max pump
VALVE	leak	12	1.00E-08	A	1.20E-07	287	18.99%	0.00E+00	0	0	0	0	small leak
Trapped V reliefs	leak	12	1.00E-05	A	1.20E-04	0	21.00%	0.00E+00	0	0	0	0	circleseal leak=0 below reseal P
Argon Loop w/o vent.													
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	287	0.00%	1.00E+00	4.47E-12	0	4.47E-12	0	
PIPES < 2"	leak, large	100	0.00E+00	B	0.00E+00	1703	0.00%	1.00E+00	0	0	0	0	
PIPES < 2"	break	100	9.14E-12	B	9.14E-10	1703	0.00%	1.00E+00	1.34E-13	0	1.34E-13	0	
Flanges	leak	12	4.00E-07	B	4.80E-06	287	0.00%	1.00E+00	7.03E-10	0	7.03E-10	0	
Flanges	blowout	12	0.00E+00	B	0.00E+00	1703	0.00%	1.00E+00	0	0	0	0	
Flanges	break	12	1.00E-09	B	1.20E-08	1703	0.00%	1.00E+00	1.76E-12	0	1.76E-12	0	
VALVE	leak	12	1.00E-08	A	1.20E-07	287	0.00%	1.00E+00	1.76E-11	0	1.76E-11	0	
Trapped V reliefs	leak	12	1.00E-05	A	1.20E-04	0	21.00%	0.00E+00	0	0	0	0	
Vent Pipes w/ vent.													
PIPES, < 2"	leak, small	300	3.05E-10	B	9.15E-08	3	20.98%	0.00E+00	0	0	0	0	
PIPES, < 2"	leak, large	300	0.00E+00	B	0.00E+00	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
PIPES, < 2"	break	300	9.14E-12	B	2.74E-09	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
PIPES, > 2"	leak, small	30	3.05E-10	B	9.15E-09	3	20.98%	0.00E+00	0	0	0	0	
PIPES, > 2"	leak, large	30	3.05E-11	B	9.15E-10	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
PIPES, > 2"	break	30	9.14E-12	B	2.74E-10	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
Flanges	leak	12	4.00E-07	B	4.80E-06	3	20.98%	0.00E+00	0	0	0	0	
Flanges	blowout	12	0.00E+00	B	0.00E+00	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
Flanges	break	12	1.00E-09	B	1.20E-08	33	20.77%	0.00E+00	0	0	0	0	limited by boil-up
VALVE	leak	12	1.00E-08	A	1.20E-07	3	20.98%	0.00E+00	0	0	0	0	
Vent Pipes w/o vent.													
PIPES, < 2"	leak, small	300	3.05E-10	B	9.15E-08	3	0.00%	1.00E+00	1.34E-11	0	1.34E-11	0	
PIPES, < 2"	leak, large	300	0.00E+00	B	0.00E+00	33	0.00%	1.00E+00	0	0	0	0	
PIPES, < 2"	break	300	9.14E-12	B	2.74E-09	33	0.00%	1.00E+00	4.01E-13	0	4.01E-13	0	
PIPES, > 2"	leak, small	30	3.05E-10	B	9.15E-09	3	0.00%	1.00E+00	1.34E-12	0	1.34E-12	0	
PIPES, > 2"	leak, large	30	3.05E-11	B	9.15E-10	33	0.00%	1.00E+00	1.34E-13	0	1.34E-13	0	
PIPES, > 2"	break	30	9.14E-12	B	2.74E-10	33	0.00%	1.00E+00	4.01E-14	0	4.01E-14	0	
Flanges	leak	12	4.00E-07	B	4.80E-06	3	0.00%	1.00E+00	7.03E-10	0	7.03E-10	0	
Flanges	blowout	12	0.00E+00	B	0.00E+00	33	0.00%	1.00E+00	0	0	0	0	
Flanges	break	12	1.00E-09	B	1.20E-08	33	0.00%	1.00E+00	1.76E-12	0	1.76E-12	0	
VALVE	leak	12	1.00E-08	A	1.20E-07	3	0.00%	1.00E+00	1.76E-11	0	1.76E-11	0	
Sample Tubing w/ vent.													
Small Dia. Tubing	leak, small	300	3.05E-10	B	9.15E-08	200	19.60%	0.00E+00	0	0	0	0	
Small Dia. Tubing	leak, large	300	0.00E+00	B	0.00E+00	200	19.60%	0.00E+00	0	0	0	0	
Small Dia. Tubing	break	300	3.05E-10	B	9.15E-08	200	19.60%	0.00E+00	0	0	0	0	
Sample Tubing w/o vent.													
Small Dia. Tubing	leak, small	300	3.05E-10	B	9.15E-08	200	0.00%	1.00E+00	1.34E-11	0	1.34E-11	0	
Small Dia. Tubing	leak, large	300	0.00E+00	B	0.00E+00	200	0.00%	1.00E+00	0	0	0	0	
Small Dia. Tubing	break	300	3.05E-10	B	9.15E-08	200	0.00%	1.00E+00	1.34E-11	0	1.34E-11	0	

PC4		
	Total Fatality Rate:	6.579E-08
	Overall ODH Class:	0

No credit taken for PC3 ventilation.

PC3		
	Total Fatality Rate:	3.505E-08
	Overall ODH Class:	0

Yellow hightlight on release rates greater than total ventilation exhaust - for reference
Yellow hightlight on ODH Class if greater than Class 0

SOURCES

A FESHM Chapter 5064, rev. 05/2009
B Risk Analysis for Process Plant, Pipelines and Transport, 1994.
C Guidelines for Process Equipment Reliability Data, with Data Tables, CCPS, 1989
D Source C and B are combined to provide a conservative failure rate and reasonable difference between failure risk and leak risk.
E Vendor service life data used to calculate a failure rate.

NOTES

1 Piping risk data is per ft per hour. Number of items for piping is estimated number of feet of piping. For piping with many bends or fittings, the estimate is increased by 50% to account for increased complexity. Outside piping is excluded.
2 Small leak and break risk for 2" to 6" is same as for less 2".
3 cryostat relief vents outside

APPENDIX A CONTENTS

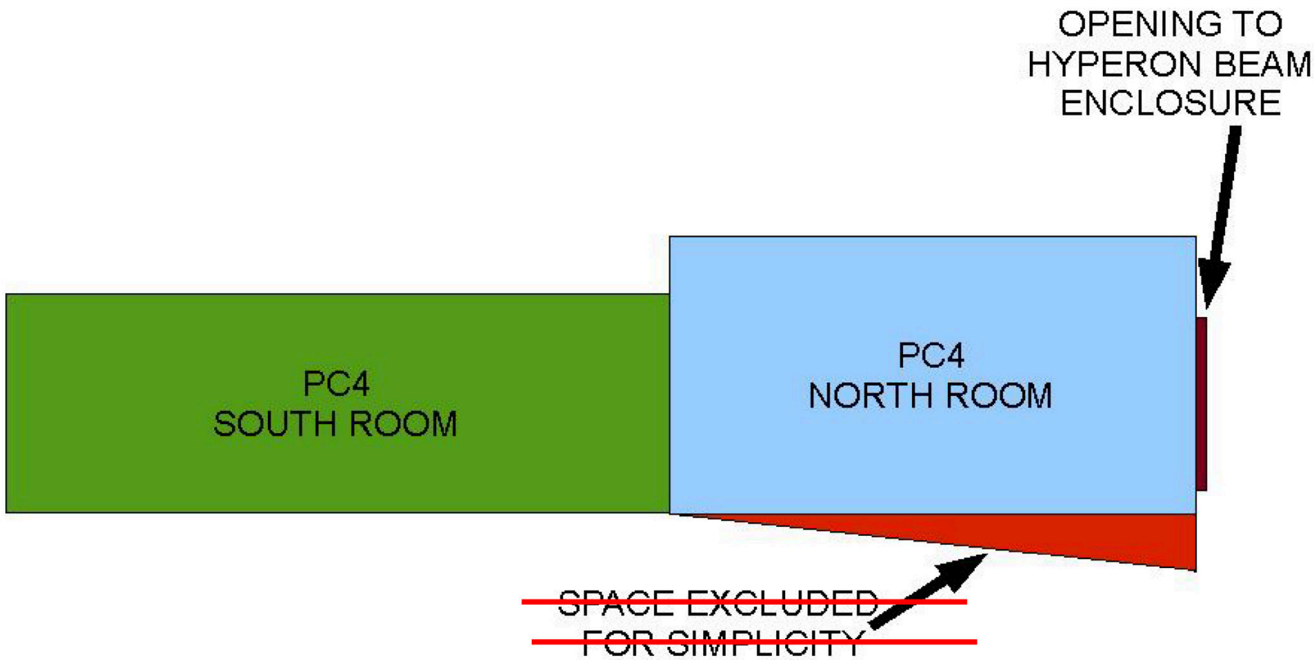
~~rev. 05-06-11~~

Piping and flange probability of failure rates now in 5064.

PC4 Volume

PC4 (P Central in original drawings) is comprised of 3 distinct sections, with no partitions or walls separating the sections.

~~For simplicity only the 2 large rooms are included in the volume calculation.~~



Height (for ODH Analysis)

$H := 6 \cdot ft = 1.83\,m$

LAPD is working with heavier than air gases so only the floor to 6 ft, people space is used for the ODH analysis.

PC4 Room dimension data from Drawing 8-4-4-PS-2, Rev A/B, Jan 4, 1974, Titled Proton Laboratory Phase G.

APPENDIX A

South Section

$L_S := 100 \cdot ft = 30.48 \cdot m$

$W_S := 28 \cdot ft = 8.53\,m$

$V_{south} := L_S \cdot W_S \cdot H$

$V_{south} = 16800 \cdot ft^3$

$V_{south} = 475.72 \cdot m^3$

North Section

$L_N := 80.5 \cdot ft = 24.54\,m$

$W_N := 43 \cdot ft = 13.11\,m$

$V_{north} := L_N \cdot W_N \cdot H$

$V_{north} = 20769 \cdot ft^3$

$V_{north} = 588.11\,m^3$

Hyperon Enclosure

$L_H := 180 \cdot ft = 54.86\,m$

$W_H := 21 \cdot ft = 6.4\,m$

$V_{hyperon} := L_H \cdot W_H \cdot H$

$V_{hyperon} = 22680 \cdot ft^3$

$V_{hyperon} = 642.23\,m^3$

Total PC4 Volume

The Hyperon Enclosure is not counted as part of the PC4 space even though it has no wall or partition separating it.

$V_{PC4} := V_{south} + V_{north}$ **+ V.hyperon**

$\cancel{V_{PC4} = 37569 \cdot ft^3}$ **V.PC4=60249 ft3**

$\cancel{V_{PC4} = 1063.84\,m^3}$

ODH Blower Failure Rate

The ODH exhaust blower fails **IF**
the power fails **OR**
the motor fails **OR**
a fuse prematurely opens **OR**
an ODH monitor fails **OR**
the ODH control panel fails.

General failure rate data from FESHM 5064.

Note: All failure rates are per hour

Electrical Power Failure

$F_{elec.pow} := 10^{-4}$ per hr

Fuse - Premature Open

$F_{fuse.p\_open} := 10^{-6}$ per hr

Electric Motor - Failure to Run - Normal Envir. (fan motor inside PC4 building)

$F_{elec.mot.norm} := 10^{-5}$ per hr

ODH Monitoring System Failure

The ODH monitor is an MSA Ultima XE/XL oxygen monitor with an MSA Gasguard XL control panel.

The sum of all IEC 61508 failures including non-dangerous failures are used for the oxygen monitor. Ref: Exida certificate MSA 080314 C001, p2.

For the control panel, the total EN 50402 failures is used.
Ref: Physical Technical Testing Institute, certificate FTZU 07 ATEX 0066X,Supplement 3, p2.

$F_{ODH.mon} := (201 + 4965 + 458)\cdot 10^{-9} = 5.62 \times 10^{-6}$ per hr

$F_{ODH.panel} := 29786\cdot 10^{-9} = 2.98 \times 10^{-5}$ per hr

Exhaust Blower Failure Rate

$F_{elec.pow} + F_{elec.mot.norm} + F_{fuse.p\_open} + F_{ODH.mon} + F_{ODH.panel} = 1.464 \times 10^{-4}$ per hr

Filter Drain / Vent Valve - Human Error Analysis

An Argon release would occur if an operator misreads a tag and opens the drain / vent valve by mistake, for one of the filter vessels while the system contains Argon.

Filter changes or regenerations are not a daily operation. Handling of the filters will be covered by written procedures that will reference tagged valves.

It is assumed that 98% of the operating time for LAPD does not involve filter changes or regenerations.

Failure rate data from FESHM 5064, Table 3.

Human Error of Commission

$$Err_{Human} := \frac{3 \cdot 10^{-3}}{24}$$ per hr

It is assumed that there would be a need (demand) for someone to select a valve once per 24 hour period for a filter media change-over. With this assumption, the error rate can be represented on a per hour basis.

Normal Operation Time
(Without Filter Changer or Regen, as percentage)

$$Normal_{op} := 98 \cdot \%$$

Filter Manual Valve Opened - Error Rate

$$F_{MVO} := Err_{Human} \cdot \left(1 - Normal_{op}\right) = 2.5 \times 10^{-6}$$ per hr

Tank / Vessel Failure

The tank failure rates here are higher than the latest 5064 (06/2012) and have been left as is.

Several sources of tank / vessel catastrophic failure data were reviewed and evaluated. All failure data was converted to a per hour failure rate.

From: Guidelines for Process Equipment Reliability Data (Center for Chemical Process Safety, 1989)

This source has mean catastrophic failures, reported as failures per 10^6 hours. These failure rates per million hours are converted to failure rates per hour.

Pressurized Vessel, Mean Failures

$$\frac{0.0109}{10^{6}\cdot \text{hrs}} = 1.09\times 10^{-8} \quad \text{per hr}$$

Atmosphere Vessel, Mean Failures (basic tank - no radiography)

$$\frac{0.985}{10^{6}\cdot \text{hrs}} = 9.85\times 10^{-7} \quad \text{per hr}$$

From: Risk Analysis for Process Plant, Pipelines and Transport, 1st ed

This source has catastrophic failure rates, reported as failures per annum and failures per 10^6 hours.

Pressurized Vessel, Mean Failures

The source listed failure rate data per annum and per 10^6 hours. Both are shown converted to per hour.

$$\frac{\left(3\cdot 10^{-6}\right)}{365\cdot 24} = 3.42\times 10^{-10} \quad \text{per hr}$$

$$\frac{2.5\times 10^{-4}}{10^{6}\cdot \text{hrs}} = 2.5\times 10^{-10} \quad \text{per hr}$$

Pressurized Vessel, Small Leak

The source listed failure rate data per annum and per 10^6 hours. Both are shown converted to per hour.

$$\frac{\left(3\cdot 10^{-5}\right)}{365\cdot 24} = 3.42\times 10^{-9} \quad \text{per hr}$$

$$\frac{2.5\times 10^{-3}}{10^{6}\cdot \text{hrs}} = 2.5\times 10^{-9} \quad \text{per hr}$$

Note that the difference between the vessel failure rate and the vessel leak rate is an order of magnitude.

The Center for Chemical Process Safety (CCPS) failure rate is more conservative. The two sources will be combined, using the more conservative CCPS failure rate combined with the order of magnitude difference to delineate between vessel catastrophic failure and vessel leak.

Piping Failure Rate

Obsolete - piping probabilties now part of 5064.

Piping can fail by developing a leak or totally breaking.

From: Risk Analysis for Process Plant, Pipelines and Transport, 1st ed

This source has failure rates for small piping (<2 inches), reported as failures per 10^6 hours, per meter of pipe. These failure rates, per million hours, per meter of pipe are converted to failure rates per hour per foot of pipe.

The failure rates are for small leak, large leaks and pipe breaks.

A small Leak is defined as a small crack or pinhole, 10 mm^2 or less.

A large Leak is defined as a crack or hole, 10 mm^2 to 1000 mm^2. An average of 500 mm^2 is assumed as the large leak size.

The 1000 mm^2 high end was specifically not used because cryogenic service lacks the pipe wall thinning conditions implied in the source data. It would be appropriate to use the high end for services that suffer from corrosion, erosion, embrittlement or chemical attack.

Small Leak, in Pipe <2"

$$\frac{\frac{0.001}{10^6 \cdot hrs}}{m} = 3.05 \times 10^{-10} \cdot ft^{-1} \quad \text{per hr}$$

Large Leak, in Pipe <2"

$$\frac{\frac{0.0001}{10^6 \cdot hrs}}{m} = 3.05 \times 10^{-11} \cdot ft^{-1} \quad \text{per hr}$$

Break, in Pipe <2"

$$\frac{\frac{0.00003}{10^6 \cdot hrs}}{m} = 9.14 \times 10^{-12} \cdot ft^{-1} \quad \text{per hr}$$

Notes on Piping Failure Rate Data

Obsolete - piping probabilties now part of 5064.

Chemical plants and petroleum refineries failure data reflects the failures of the piping in those environments.

Those environments include;
- outdoor, year round operation
- high temperature (decreasing strength) and pressure
- large temperature range operation - crude cracking to liquefying gases
- stress cracks and embrittlement due to high temperature chemical attack
- surface corrosion, inside and outside surfaces
- chemical attack of gasketing materials
- frequent operation at eroding line velocities

Cryogenic operations of concern for ODH are indoors. The cryogens contained are not corrosive to the metals and gasketing materials used. Cryogenic operation is in the direction of higher metal strength (decreasing temperature).

Cryogenic operation is different from chemical/refinery operation but at the same time suffers from fewer sources of failure over time.

The chemical/refinery failure data will be used even though it reflects failures from additional sources not seen in cryogenic service.

Flange (Traditional) Failure Rate

Obsolete - piping probabilties now part of 5064.

Flanges can fail by developing a leak, blowing packing or breaking open.

From: Risk Analysis for Process Plant, Pipelines and Transport, 1st ed

This source has failure rates reported as failures per m per 10^6 hours.

The reported failure rates include failure modes such as flange corrosion, packing corrosion, overstressing due to heating and aging of packing. The corrosion and overstressing from heating do not apply to cyrogenic service. The metal gaskets that will be used do not degrade with age. To account for these differences, the reported data for packing blowout and flange break will be reduced by an order of magnitude.

Flange Leak

$$\frac{0.4}{10^{6}\cdot hrs} = 4.0\times 10^{-7}$$ per hr

Flange Packing Blowout

$$\frac{\frac{0.03}{10^{6}\cdot hrs}}{10} = 3.0\times 10^{-9}$$ per hr

Flange Breaks Open

$$\frac{\frac{0.01}{10^{6}\cdot hrs}}{10} = 1.0\times 10^{-9}$$ per hr

Obsolete - piping probabilties now part of 5064.

Flange (CF - Conflat) Failure Rate

Conflat flanges are used in cryogenic service because these flanges offer superior low leak performance. The flange faces have a knife edge that is compressed into a metal gasket to provide a annular groove that provides a reliable leak tight seal. The metal gasket ring is a softer metal such as copper, which flows into surface imperfections as it is compressed. This annular groove seal is capable of withstanding high vacuum, or pressure, even after repeated thermal cycling. For maximum tightness, higher bolt count conflat flanges are used.

In the absense of conflat specific failure data, the flange failure rates will be used.

Pipe leaks and Break - Argon Pump Loop

This calculation determines the Argon leak rate for a small leak (10 mm^2), a large leak (10 mm^2 to 1000 mm^2) and a pipe break. The available pressure is taken as the discharge pressure of the Argon pump. This results in the worst case Argon flows. The calculations are performed as flow across an orifice of the leak or pipe size.

The maximum flow is limited by the throughput of the pump.

Argon Data

Argon physical properties from NIST REFPROP

Argon Liquid Density

$$Ldens_{Ar} := 1395 \cdot \frac{kg}{m^3}$$

Argon Gas Density @ standard conditions

$$Vdens_{Ar.STD} := 0.10535 \cdot \frac{lbm}{ft^3} = 1.68755 \cdot \frac{kg}{m^3}$$

$$Vdens_{Ar.cold} := 6.85 \cdot \frac{kg}{m^3}$$ saturated @ 3 psig

Max. Available Pressure - Across Orifice (tank design P + tank liquid head+ pump head)

$$\Delta P := \left[3 \cdot psi + \left(10ft \cdot g \cdot Ldens_{Ar}\right) + 4.25 \cdot bar\right] - 0 \cdot psi = 70.7 \cdot psi$$

ref: BNCP-32B Liquid Argon Pump Curve, LARTPC DOC 474-v1, highest differential.

Orifice Flow Coefficient (square edged orifice)

$$C := 0.62$$

Pipe ID - 1" sched 10

$$Pipe_{ID} := 1.097 \cdot in$$

$$Area_{pipe} := \pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2 = 0.945 \cdot in^2$$

$$Area_{S.leak} := 10 \cdot mm^2 = 0.0155 \cdot in^2$$

$$Area_{L.leak} := 500 \cdot mm^2 = 0.775 \cdot in^2$$

Average large leak size will be used for the calcs.

Full Argon Pump flow to Gas (taken as end of vendor pump curve)

$$gasflow_{pump.limit} := 3500 \cdot \frac{L}{hr} \cdot \frac{Ldens_{Ar}}{Vdens_{Ar.STD}} = 1703 \cdot \frac{ft^3}{min}$$

ref: BNCP-32B Liquid Argon Pump Curve, LARTPC DOC 474-v1.

$$gasflow_{pump.limit} = 48 \cdot \frac{m^3}{min}$$

Per pump vendor pump flow will not exceed 3500 LPH. Pump performance drops off rapidly moving to right on the pump curve.

Flow from Pipe Break - Argon Pump Loop

$$Leak_{Ar.brk} := \frac{\left(C \cdot Area_{pipe} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar} \right)}{Vdens_{Ar.STD}}$$

$$Leak_{Ar.brk} = 495.76 \cdot \frac{m^3}{min}$$

$$Leak_{Ar.brk} = 17507.76 \cdot \frac{ft^3}{min}$$

This exceeds pumping capacity, therefore will use pumping capacity.

$$gasflow_{pump.limit} = 1703 \cdot \frac{ft^3}{min}$$

Flow from Small Leak - Argon Pump Loop

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar} \right)}{Vdens_{Ar.STD}} = 287 \cdot \frac{ft^3}{min}$$

~~Flow from Large Leak - Argon Pump Loop~~

Only the small leak and pipe break are credible for pipes 2" or small - 5064 (06/2012)

$$\cancel{\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar} \right)}{Vdens_{Ar.STD}} = 14356 \cdot \frac{ft^3}{min}}$$

$$\cancel{gasflow_{pump.limit} = 1703 \cdot \frac{ft^3}{min}}$$

~~This exceeds pumping capacity, therefore will use pumping capacity.~~

Flow from Small Flange Leak - Argon

$$\frac{\left(C\cdot Area_{S.leak}\cdot\sqrt{2\cdot g\cdot\frac{\Delta P\cdot 1\frac{lbm}{lbf}}{Ldens_{Ar}}}\cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 287\cdot\frac{ft^3}{min}$$

The small leak area is taken as the same as for a small pipe leak.

~~Flow from Flange Packing Blowout - Argon~~

~~Assuming that 30% of pipe ID becomes a leak with a 1 mm gap.~~

$$Pipe_{ID} = 1.097\cdot in$$

$$Area_{pack.leak} := 30\%\cdot(2\pi\cdot Pipe_{ID})\cdot 1\cdot mm = 0.08141\cdot in^2$$

Rope gasket not used and therefore gasket blowout not credible for cryogen piping - 5064 (06/2012)

$$\frac{\left(C\cdot Area_{pack.leak}\cdot\sqrt{2\cdot g\cdot\frac{\Delta P\cdot 1\frac{lbm}{lbf}}{Ldens_{Ar}}}\cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 1508\cdot\frac{ft^3}{min}$$

~~This exceeds pumping capacity, therefore will use pumping capacity.~~

Flow from Flange Break - Argon

Assuming that 100% of pipe ID becomes a leak with a 2 mm gap.

$$Area_{flg.break} := 100\%\cdot(2\pi\cdot Pipe_{ID})\cdot 2\cdot mm = 0.54273\cdot in^2$$

$$\frac{\left(C\cdot Area_{flg.break}\cdot\sqrt{2\cdot g\cdot\frac{\Delta P\cdot 1\frac{lbm}{lbf}}{Ldens_{Ar}}}\cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 10053\cdot\frac{ft^3}{min}$$

$$gasflow_{pump.limit} = 1703\cdot\frac{ft^3}{min}$$

This exceeds pumping capacity, therefore will use pumping capacity.

Pipe Leaks and Break - Argon Vent Pipe

This calculation determines the Argon leak rate for a small leak (10 mm^2), a large leak (10 mm^2 to 1000 mm^2) and a pipe break. The available pressure for vents pipes is 1 psig or less. The calculations are performed as flow across an orifice of the leak or pipe size.

Available Pressure - Across Orifice

$$\Delta P := 2 \cdot psi - 0 \cdot psi$$

Pipe ID - 3" sched 10

$$Pipe_{ID} := 3.260 \cdot in \qquad Area_{pipe} := \pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2 = 8.347 \cdot in^2$$

Max Argon Vapor (Boil-up Rate)

ref: LArtPC DOCDB DOC 475, LAPD Tank Absorbed Heat

Argon Heat of Vaporization $Hv := 161. \cdot \frac{kJ}{kg}$

$$Max\_Ar_{boilup} := \frac{\frac{2 \cdot 2100 \cdot W}{Hv}}{Vdens_{Ar.STD}} = 32.75 \cdot \frac{ft^3}{min}$$

Flow from Pipe Break - Argon Vent Pipe

$$\frac{\left(C \cdot Area_{pipe} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{Ar.cold}}} \cdot Vdens_{Ar.cold}\right)}{Vdens_{Ar.STD}} = 1822 \cdot \frac{ft^3}{min}$$

Exceeds max boil-up therefore use max boil-up rate. $Max\_Ar_{boilup} = 32.75 \cdot \frac{ft^3}{min}$

Flow from Small Leak - Argon Vent Pipe

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{Ar.cold}} \cdot Vdens_{Ar.cold}}\right)}{Vdens_{Ar.STD}} = 3 \cdot \frac{ft^3}{min}$$

Exceeds max boil-up therefore use max boil-up rate.

$$Max\_Ar_{boilup} = 32.75 \cdot \frac{ft^3}{min}$$

Flow from Large Leak - Argon Vent Pipe

$$\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{Ar.cold}} \cdot Vdens_{Ar.cold}}\right)}{Vdens_{Ar.STD}} = 169 \cdot \frac{ft^3}{min}$$

Exceeds max boil-up therefore use max boil-up rate.

$$Max\_Ar_{boilup} = 32.75 \cdot \frac{ft^3}{min}$$

APPENDIX A

Flow from Small Flange Leak - Argon Vent Pipe

$$\frac{\left(C\cdot Area_{S.leak}\cdot\sqrt{2\cdot g\cdot\frac{\Delta P\cdot 1\frac{lbm}{lbf}}{Vdens_{Ar.cold}}}\cdot Vdens_{Ar.cold}\right)}{Vdens_{Ar.STD}} = 3\cdot\frac{ft^3}{min}$$

The small leak area is taken as the same as for a small pipe leak.

~~Flow from Flange Packing Blowout - Argon Vent Pipe~~

~~Assuming that 30% of pipe ID becomes a leak with a 1 mm gap.~~

$$Pipe_{ID} = 3.26\cdot in$$

$$Area_{pack.leak} := 30\%\cdot\left(2\pi\cdot Pipe_{ID}\right)\cdot 1\cdot mm = 0.24193\cdot in^2$$

Rope gasket not used and therefore gasket blowout not credible for cryogen piping - 5064 (06/2012)

$$\frac{\left(C\cdot Area_{pack.leak}\cdot\sqrt{2\cdot g\cdot\frac{\Delta P\cdot 1\frac{lbm}{lbf}}{Vdens_{Ar.cold}}}\cdot Vdens_{Ar.cold}\right)}{Vdens_{Ar.STD}} = 53\cdot\frac{ft^3}{min}$$

~~Exceeds max boil-up therefore use max boil-up rate.~~

$$Max\_Ar_{boilup} = 32.75\cdot\frac{ft^3}{min}$$

Flow from Flange Break - Argon Vent Pipe

Assuming that 100% of pipe ID becomes a leak with a 2 mm gap.

$$Area_{flg.break} := 100\%\cdot\left(2\pi\cdot Pipe_{ID}\right)\cdot 2\cdot mm = 1.61285\cdot in^2$$

$$\frac{\left(C\cdot Area_{flg.break}\cdot\sqrt{2\cdot g\cdot\frac{\Delta P\cdot 1\frac{lbm}{lbf}}{Vdens_{Ar.cold}}}\cdot Vdens_{Ar.cold}\right)}{Vdens_{Ar.STD}} = 352\cdot\frac{ft^3}{min}$$

Exceeds max boil-up therefore use max boil-up rate.

$$Max\_Ar_{boilup} = 32.75\cdot\frac{ft^3}{min}$$

APPENDIX A

Conflat Leaks and Breaks - Argon Vapor

This calculation determines the Argon leak rate for conflat leaks. Use of conflats is assumed to be limited to service that would only see argon gas at cryostat vapor space pressure. The available pressure from the cryostat vapor space is 3 psig or less. The calculations are performed as flow across an orifice of the leak or pipe size.

Available Pressure - Across Orifice

$$\Delta P := (3.0 \cdot psi) - 0 \cdot psi$$

Argon Gas Density (Saturated @ 3 psig)

$$Vdens_{Ar.cold} = 6.85 \cdot \frac{kg}{m^3}$$

Pipe ID - 4" sched 10

$$Pipe_{ID} := 4.260 \cdot in \qquad Area_{pipe} := \pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2 = 14.253 \cdot in^2$$

Flow from Small Conflat Leak - Argon Vapor

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{Ar.cold}} \cdot Vdens_{Ar.cold}}\right)}{Vdens_{Ar.STD}} = 4 \cdot \frac{ft^3}{min}$$

The small leak area is taken as the same as for a small pipe leak.

~~Flow from Conflat Packing Blowout - Argon Vapor~~

~~Conflat gasket (packing) is a softer metal that can deform but would not be subject to true packing blowout. Assuming that 30% of pipe ID becomes a leak with a 0.25 mm gap, even though the knife edge seal prevents this.~~

$$Pipe_{ID} = 4.26 \cdot in$$

$$Area_{pack.leak} := 25\% \cdot (2\pi \cdot Pipe_{ID}) \cdot 0.25 \cdot mm = 0.06586 \cdot in^2$$

$$\frac{\left(C \cdot Area_{pack.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{Ar.cold}} \cdot Vdens_{Ar.cold}}\right)}{Vdens_{Ar.STD}} = 18 \cdot \frac{ft^3}{min}$$

Rope gasket not used and therefore gasket blowout not credible for cryogen piping - 5064 (06/2012)

Flow from Conflat Break - Argon Vapor

Assuming that 100% of pipe ID becomes a leak with a 1/2 mm gap. The tight fit and knife edge seal reduces the gap potential compared to traditional flanges.

$$Area_{flg.break} := 100\% \cdot (2\pi \cdot Pipe_{ID}) \cdot \frac{1}{2} \cdot mm = 0.5269 \cdot in^2$$

$$\frac{\left(C \cdot Area_{flg.break} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{Ar.cold}} \cdot Vdens_{Ar.cold}}\right)}{Vdens_{Ar.STD}} = 141 \cdot \frac{ft^3}{min}$$

Exceeds max boil-up therefore use max boil-up rate. $Max\_Ar_{boilup} = 32.75 \cdot \frac{ft^3}{min}$

LAPD Tank Leaks

This calculation determines the Argon leak rate for a small leak (10 mm^2).

The available pressure is significantly lower than that of the Argon pump loop.
The calculations are performed as flow across an orifice of the leak or pipe size.
The leak is assumed to occur below full liquid level.

Max. Available Pressure - Across Orifice (tank design P + tank liquid head)

$$\Delta P := \left[3 \cdot psi + \left(10ft \cdot g \cdot Ldens_{Ar}\right)\right] - 0 \cdot psi \qquad \Delta P = 9.05 \cdot psi$$

$$Area_{T.leak} := 10 \cdot mm^2 = 0.0155 \cdot in^2$$

This assumes the leak occurs near the bottom of tank and therefore sees the full liquid head.

Flow from Tank Leak

$$\frac{\left(C \cdot Area_{T.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 103 \cdot \frac{ft^3}{min}$$

Flow from Tank Failure

A tank failure is taken as a leak equal to the largest available piping port below the liquid level. On the LAPD tank the largest below liquid port is a 2" sch-40, which has a pipe ID of 2.067 inches.

$$\frac{\left[C \cdot \pi \cdot \left(\frac{2.067 \cdot in}{2}\right)^2 \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right]}{Vdens_{Ar.STD}} = 22240 \cdot \frac{ft^3}{min}$$

Calc of Liquid Nitrogen pipe leaks and break

This calculation determines the Nitrogen leak rate for a small leak (10 mm^2), a large leak (10 mm^2 to 1000 mm^2) and a pipe break. The available pressure is taken as high side of the Nitrogen trailer delivery pressure range. This results in the worst case Nitrogen flows. The calculations are performed as flow across an orifice of the leak or pipe size.

N2 Data

Physical properties from NIST REFPROP

N2 Liquid Density

$Ldens_{N2} := 807 \cdot \frac{kg}{m^3}$

N2 Gas Density @ standard conditions

$Vdens_{N2.STD} := 1.183 \cdot \frac{kg}{m^3}$

Available Pressure - Across Orifice

$\Delta P := 30 \cdot psi - 0 \cdot psi$

Orifice Flow Coefficient (square edged orifice)

$C := 0.62$

Pipe ID - 1", K Copper Tube

$Pipe_{ID} := 0.995 \cdot in$

$Area_{pipe} := \pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2 = 0.778 \cdot in^2$

$Area_{S.leak} := 10 \cdot mm^2 = 0.0155 \cdot in^2$

$Area_{L.leak} := 500 \cdot mm^2 = 0.775 \cdot in^2$

Average large leak size will be used for the calcs.

Flow from Pipe Break - LN2 Pipe

$$\frac{\left(C \cdot Area_{pipe} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 10180 \cdot \frac{ft^3}{min}$$

Flow from Small Leak - LN2 Pipe

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 203 \cdot \frac{ft^3}{min}$$

~~Flow from Large Leak - LN2 Pipe~~

Only the small leak and pipe break are credible for pipes 2" or small - 5064 (06/2012)

$$\cancel{\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 10147 \cdot \frac{ft^3}{min}}$$

APPENDIX A

Flow from Small Flange Leak - Liquid Nitrogen

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 203 \cdot \frac{ft^3}{min}$$

The small leak area is the same as for a small pipe leak.

~~Flow from Flange Packing Blowout - Liquid Nitrogen~~

~~Assuming that 30% of pipe ID becomes a leak with a 1 mm gap.~~

$$Pipe_{ID} = 0.995 \cdot in$$

$$Area_{pack.leak} := 30\% \cdot (2\pi \cdot Pipe_{ID}) \cdot 1 \cdot mm = 0.07384 \cdot in^2$$

$$\frac{\left(C \cdot Area_{pack.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 967 \cdot \frac{ft^3}{min}$$

Rope gasket not used and therefore gasket blowout not credible for cryogen piping - 5064 (06/2012)

Flow from Flange Break - Liquid Nitrogen

Assuming that 100% of pipe ID becomes a leak with a 2 mm gap.

$$Area_{flg.break} := 100\% \cdot (2\pi \cdot Pipe_{ID}) \cdot 2 \cdot mm = 0.49227 \cdot in^2$$

$$\frac{\left(C \cdot Area_{flg.break} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 6445 \cdot \frac{ft^3}{min}$$

Pipe Leaks and Breaks - Nitrogen Gas

This calculation determines the Nitrogen leak rate for a small leak (10 mm^2), a large leak (10 mm^2 to 1000 mm^2) and a pipe break. The calculations are performed as flow across an orifice of the leak or pipe size.

N2 Data

Physical properties from NIST REFPROP

N2 Vapor Density (saturated @ 5 psig

$$Vdens_{N2} := 6.05 \cdot \frac{kg}{m^3}$$

N2 Gas Density @ standard conditions

$$Vdens_{N2.STD} := 1.183 \cdot \frac{kg}{m^3}$$

Available Pressure - Across Orifice

$$\Delta P := 30 \cdot psi - 0 \cdot psi$$

Orifice Flow Coefficient (square edged orifice)

$$C := 0.62$$

Pipe ID - 2", sched 10

$$Pipe_{ID} := 2.157 \cdot in$$

$$Area_{pipe} := \pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2 = 3.654 \cdot in^2$$

$$Area_{S.leak} := 10 \cdot mm^2 = 0.0155 \cdot in^2$$

$$Area_{L.leak} := 500 \cdot mm^2 = 0.775 \cdot in^2$$

Average large leak size will be used for the calcs.

APPENDIX A

Flow from Pipe Break - Nitrogen Gas

$$\frac{\left(C \cdot Area_{pipe} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{N2}}} \cdot Vdens_{N2}\right)}{Vdens_{N2.STD}} = 4142 \cdot \frac{ft^3}{min}$$

Flow from Small Leak - Nitrogen Gas

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{N2}}} \cdot Vdens_{N2}\right)}{Vdens_{N2.STD}} = 18 \cdot \frac{ft^3}{min}$$

~~Flow from Large Leak - Nitrogen Gas~~

$$\cancel{\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{N2}}} \cdot Vdens_{N2}\right)}{Vdens_{N2.STD}} = 879 \cdot \frac{ft^3}{min}}$$

Only the small leak and pipe break are credible for pipes 2" or small - 5064 (06/2012)

Flow from Small Flange Leak - Nitrogen Gas

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{N2}} \cdot Vdens_{N2}}\right)}{Vdens_{N2.STD}} = 18 \cdot \frac{ft^3}{min}$$

The small leak area is the same as for a small pipe leak.

~~Flow from Flange Packing Blowout - Nitrogen Gas~~

~~Assuming that 30% of pipe ID becomes a leak with a 1 mm gap.~~

$$Pipe_{ID} = 2.157 \cdot in$$

$$Area_{pack.leak} := 30\% \cdot \left(2\pi \cdot Pipe_{ID}\right) \cdot 1 \cdot mm = 0.16007 \cdot in^2$$

Rope gasket not used and therefore gasket blowout not credible for cryogen piping - 5064 (06/2012)

$$\frac{\left(C \cdot Area_{pack.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{N2}} \cdot Vdens_{N2}}\right)}{Vdens_{N2.STD}} = 181 \cdot \frac{ft^3}{min}$$

Flow from Flange Break - Nitrogen Gas

Assuming that 100% of pipe ID becomes a leak with a 2 mm gap.

$$Area_{flg.break} := 100\% \cdot \left(2\pi \cdot Pipe_{ID}\right) \cdot 2 \cdot mm = 1.06715 \cdot in^2$$

$$\frac{\left(C \cdot Area_{flg.break} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Vdens_{N2}} \cdot Vdens_{N2}}\right)}{Vdens_{N2.STD}} = 1210 \cdot \frac{ft^3}{min}$$

Trapped Volume Relief - Liquid Nitrogen and Liquid Argon

Trapped volume reliefs on liquid Nitrogen and Liquid Argon will vent into the room. This calculation determines the longest length of 1" piping that can safety be vented into the room. Any trapped volumes piping sections that exceed this length will be undergo additional evaluation.

Note: Largest cryogen inventory outside of the main tank could be in a liquid full phase separator, 5 ft x 12 in dia, 29 gallon of liquid. This is insufficient to create an ODH condition.

Volume of PC4 (up to 6 ft)

$\cancel{V_{PC4} = 1063.84\,m^3}$ $\quad V_{PC4} = \cancel{37569\cdot ft^3}$

60249 ft3

Largest Instantaneous release with Fatality rate of 0

$$V_{gas.release} := V_{PC4} - \frac{18\%\cdot V_{PC4}}{21\cdot\%}$$

$\cancel{V_{gas.release} = 152.0\cdot m^3}$

8607 ft3

$V_{gas.release} = \cancel{5367\cdot ft^3}$

Liquid Volume for the Largest F=0 release

$$V_{LN2.release} := \frac{V_{gas.release}\cdot Vdens_{N2.STD}}{Ldens_{N2}}$$

$\cancel{V_{LN2.release} = 0.223\cdot m^3}$

12.617 ft3

$V_{LN2.release} = \cancel{7.868\cdot ft^3}$

$V_{LN2.release} = \cancel{58.85\cdot gal}$

94.4 gal

$$V_{LAr.release} := \frac{V_{gas.release}\cdot Vdens_{Ar.STD}}{Ldens_{Ar}}$$

$\cancel{V_{LAr.release} = 0.184\cdot m^3}$

10.412 ft3

$V_{LAr.release} = \cancel{6.493\cdot ft^3}$

$V_{LAr.release} = \cancel{48.57\cdot gal}$

77.9 gal

The liquid argon release is more conservative because it takes less liquid to reach the limits of F=0. The liquid Nitrogen trapped volume piping will be screened using the same value for simplicity.

Length of 1" pipe equivalent to the largest F=0 Release

$$L_{longest} := \frac{V_{LN2.release}}{\pi\cdot\left(\frac{1\cdot in}{2}\right)^2}$$

581.86 m

$L_{longest} = \cancel{439.67\,m}$

For 1" piping, LN2 or LAr, trapped volume piping sections with less than this length of pipe do not impact the room ODH. This is also true for 1" N2 gas and Ar gas piping. The actual gas piping can be significantly greater.

APPENDIX B - PC3 Fan "Head"

rev. 05-06-11

These calculations determine the backpressure from PC4 for the PC3 ventilation that vents into PC4.

Three cases are evaluated:
- All of PC4 @ 18% O2 from a slow argon release.
- Floor to 6 ft @ 15% O2 from a significant argon spill.
- Floor to 6 ft @ 0% O2.

Concentration of Oxygen in air

$X_o := 0.21 \cdot X_{air}$

Relationship between inert gas and air

$X_{air} := 1 - X_{inert}$

Substituting in the inert conc.

$X_o := 0.21 \cdot (1 - X_{inert})$

Rearranged to solve for inert conc.

$$X_{inert} := 1 - \frac{X_o}{0.21}$$

Case 1: Evaluate at 18% O2, floor to ceiling

$X_o := 18 \cdot \%$ $\quad X_{inert} := 1 - \frac{X_o}{0.21}$ $\quad X_{inert} = 14.3 \cdot \%$

Resulting "Air" Makeup for Density Determination

$O2_{conc} := X_o = 18 \cdot \%$ $\quad N2_{conc} := (1 - X_{inert}) \cdot 0.79 = 67.7 \cdot \%$ $\quad X_{inert} = 14.3 \cdot \%$

Density of the reduced O2 air with argon as the added inert gas
ref: REFPROP V8.0

$\rho_{mix} := 1.2610 \cdot \frac{kg}{m^3}$ @ 70 F

$\rho_{air} := 1.1559 \cdot \frac{kg}{m^3}$ air @ 90 F
(worst case is when air is warm)

Gas Head from the above added argon gas and PC4 full of this gas mixture

$Gas_{H1} := 20 \cdot ft \cdot g \cdot (\rho_{mix} - \rho_{air}) = 0.025 \cdot in\_H2O$

Case 2: Evaluate at 15% O2, floor to 6 ft

$X_o := 15 \cdot \%$ $\quad X_{inert} := 1 - \frac{X_o}{0.21}$ $\quad X_{inert} = 28.6 \cdot \%$

Resulting "Air" Makeup for Density Determination

$O2_{conc} := X_o = 15 \cdot \%$ $\quad N2_{conc} := (1 - X_{inert}) \cdot 0.79 = 56.4 \cdot \%$ $\quad X_{inert} = 28.6 \cdot \%$

Density of the reduced O2 air with argon as the added inert gas
ref: REFPROP V8.0

$\rho_{mix} := 1.4536 \cdot \frac{kg}{m^3}$ @20 F $\quad \rho_{air} = 1.1559 \cdot \frac{kg}{m^3}$ @90 F

Gas Head from the above added argon gas and PC4 full of this gas mixture

$Gas_{H2} := 6 \cdot ft \cdot g \cdot (\rho_{mix} - \rho_{air}) = 0.021 \cdot in\_H2O$

Case 3: Evaluate at 0% O2, floor to 6 ft

Density of 0% O2 / pure argon gas
ref: REFPROP V8.0

$\rho_{Argas} := 1.9087 \cdot \frac{kg}{m^3}$ @ 0 F $\quad \rho_{air} = 1.1559 \cdot \frac{kg}{m^3}$ @90 F

Gas Head from the above added argon gas and PC4 full of this gas mixture

$Gas_{H3} := 6 \cdot ft \cdot g \cdot (\rho_{Argas} - \rho_{air}) = 0.054 \cdot in\_H2O$

$Gas_{H1} = 0.025 \cdot in\_H2O$ $\quad Gas_{H2} = 0.021 \cdot in\_H2O$

Case 3 has the highest gas head and therefore case 3 sets the "head" the fan must be capable of.

The supply duct to the new PC3 fan is an existing spiral air duct. The inside diameter was field measured at 17.5 inches.

Duct Static Pressure loss for 500 cfm in 17" spiral duct

$$SP_{duct.loss} := 0.02 \cdot \frac{in\_H2O}{100 \cdot ft}$$

ref: Spiral Manufacturing Co. Engineering Data, p. 56, www.spiralmfg.com.

Total Duct Statis Pressure loss for 300 ft of duct at above flow

$$Duct_{loss} := 300 \cdot ft \cdot SP_{duct.loss} = 0.06 \cdot in\_H2O$$

Total SP for fan selection

$$Gas_{H3} + Duct_{loss} = 0.114 \cdot in\_H2O$$

Estimate of PC3 air exchange rate

PC3 is a long tunnel that is approximated 10 ft wide by 10 ft tall and approximate 200 ft in length.

$$\frac{hr}{\dfrac{10 \cdot ft \cdot 10 \cdot ft \cdot 200 \cdot ft}{500 \cdot \dfrac{ft^3}{min}}} = 1.5$$ air exchanges per hour

DAYTON Exhaust Fan, 16 In, 115 V, 1060 CFM

HVACR > Exhaust Fans > Guard Mounted Exhaust Fans

Exhaust Fan, Guard Mounted, Propeller Dia 16 In, CFM @ 0.000-In SP 1060, @ 0.125-In SP 585, Sones @ 0.000-In SP @ 5 Ft 8, Voltage 115, 60 Hz, Single Phase, Operating Amps 1.7, Motor HP 1/20, Max Ambient Temp 104 F, Max Depth 6 1/2 In, Mounting Position Vertical/Horizontal, Outside Dia 20 1/8 In

Grainger Item #	1HKL5
Price (ea.)	**$204.75**
Brand	DAYTON
Mfr. Model #	1HKL5
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	15.24
Usually Ships**	Today
Catalog Page No.	4209
Country of Origin **(Country of Origin is subject to change.)**	USA

PC3 FAN.

Qty.

Enlarge Image

Add Grainger TripleGuard® repair & replacement coverage for $55.95 each.

Add to Order | Add to Personal List | Compare Alternates

Price shown may not reflect your price. Sign in or register.

Tech Specs | Additional Information | Compliance & Restrictions | MSDS | Required Accessories | Optional Accessories | Alternate Products | Repair Parts

Item	Exhaust Fan
Type	Guard Mounted
Propeller Dia. (In.)	16
CFM @ 0.000-In. SP	1060
CFM @ 0.125-In. SP	585
Sones @ 0.000-In. SP @ 5 Ft.	8
Voltage	115
Hz	60
Phase	1
Operating Amps	1.0
Motor HP	1/20
Max. Ambient Temp. (F)	104
Bearing Type	Sleeve
Motor RPM	1550
Motor Type	Shaded Pole
Motor Enclosure	Totally Enclosed Air-Over
Motor Insulation	Class A
Max. Depth (In.)	8-3/4
Mounting Position	Horizontal or Vertical
Mounting Holes O.C. (In.)	12-15/16
Guard Material	Steel
Wire Guard Finish	Gray Polyester
Outside Dia. (In.)	17-3/8
Propeller Material	Stamped Aluminum
Number of Blades	3
Includes	Wiring, Junction Box, and 7" Leads
Agency Compliance	UL Listed for US and Canada

View Catalog Page View Printable Page

The "Usually Ships" reflects when an item is generally expected to ship from Grainger based on its stocking location. Real-time availability information will be shown during the checkout process and on the e-mail order confirmation (for U.S. and Puerto Rico - US customers only). Please allow additional delivery time for international orders.

We Also Carry

Return To Top

SWB Backward Inclined Centrifugal Utility Fan

Tag Mark 1

ENGINEERING DATA

Approx. Fan Weight (lb)	Max. T Motor Frame Size
231	184

**Fan weight is without accessories.

Drive Type
Variable

CONFIGURATION

Arrangement	Rotation	Discharge Position
10	CW	TH

INSTALLATION

Air Stream Temp. (F)
70

MOTOR SPECS

Size (hp)	RPM	V/C/P	Enclosure	Motor Frame Size	FLA (A)
3	1725	460/60/3	ODP	182	4.8

FLA - Based on tables 150 or 148 of National Electrical Code 2002.

STANDARD CONSTRUCTION FEATURES

HOUSING: Heavy gauge steel housing with Lock-seam construction • Unit support angles with prepunched mounting holes • Adjustable motor plate • Corrosion resistant fasteners • Entire unit is phosphatized and coated.
BEARINGS, SHAFT, AND WHEEL: Heavy duty lubricatable, self-aligning ball bearing pillow blocks • Polished, solid steel shafts • Backward inclined fan wheel
(Fans with EXP. motors include: aluminum wheel, aluminum rub ring, and shaft seal)

SELECTED OPTIONS & ACCESSORIES

Switch - Nema-1, Toggle, Mounted & Wired
Damper WD-340-PB-11x15, Gravity Operated
Steel Wheel Construction
Outlet Flange - Punched
Inlet Guard
Extended Lubrication Lines
Permatector - Standard Coating on Entire Fan
Weatherhood
UL/cUL-705 - "Power Ventilators"
Neoprene Isolators Indoor/Outdoor, Single Deflection 1/4"
Energy Efficient Motor meets EPACT and NEMA 1210

PC4 ODH Blower

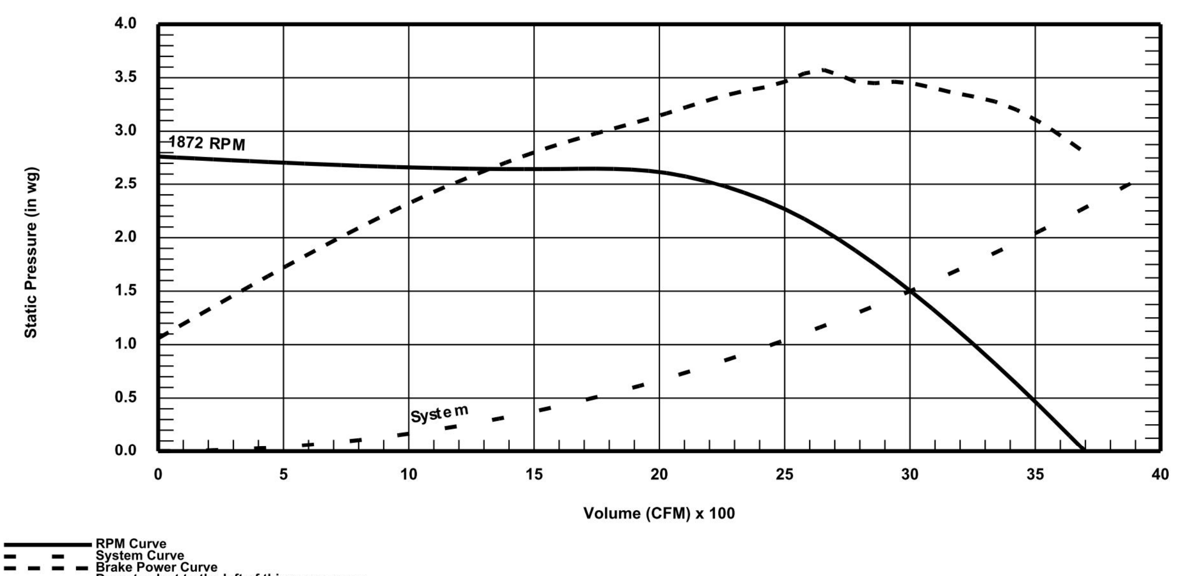
PERFORMANCE Elevation ft = 0

Qty.	Model	Volume (CFM)	SP (in wg)	TS (ft/min)	OV (ft/min)	FRPM	Operating Power (hp)	SE %
1	SWB-215-30	3,000	1.5	7,351	2,431	1,872	1.37	52

SOUND

Inlet Sound Power by Octave Band								LwA	dBA	Noise Criteria	Sones
62.5	125	250	500	1000	2000	4000	8000				
88	78	78	80	76	74	69	63	81	70	66	18.5

LwA - A weighted sound power level, based on ANSI S1.4. dBA - A weighted sound pressure level, based on 11.5 dB attenuation per octave band at 5.0 ft. Noise Criteria (NC) based on an average attenuation of 11.5 dB per octave band at 5.0 ft.



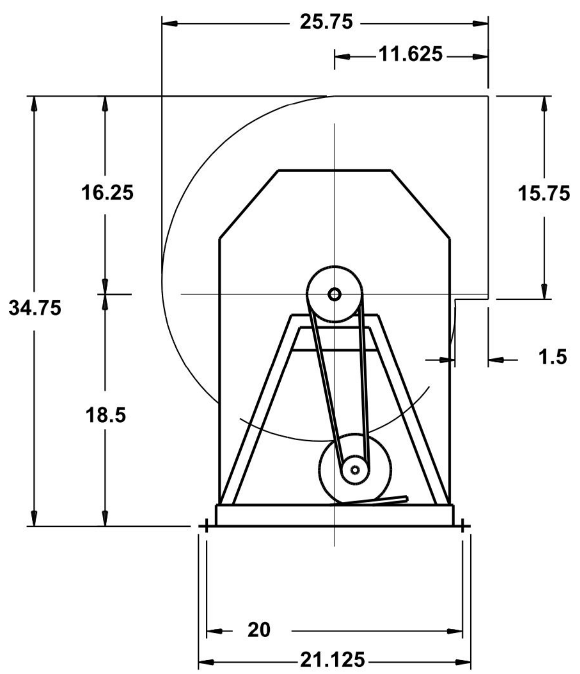
GREENHECK
Building Value in Air.

Printed Date: 1/4/2010
Job: Fermi-Argon 010410
Product Type: Fan
Mark: Mark 1

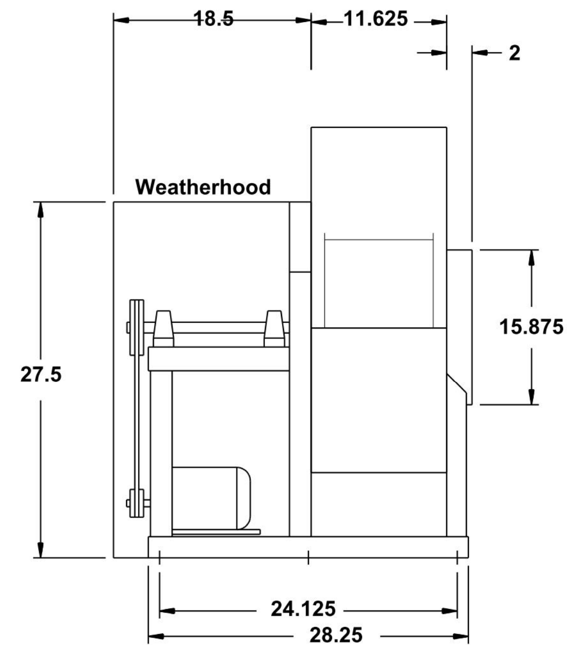
Size: 15
Arrangement: 10

SWB Backward Inclined Centrifugal Utility Fan

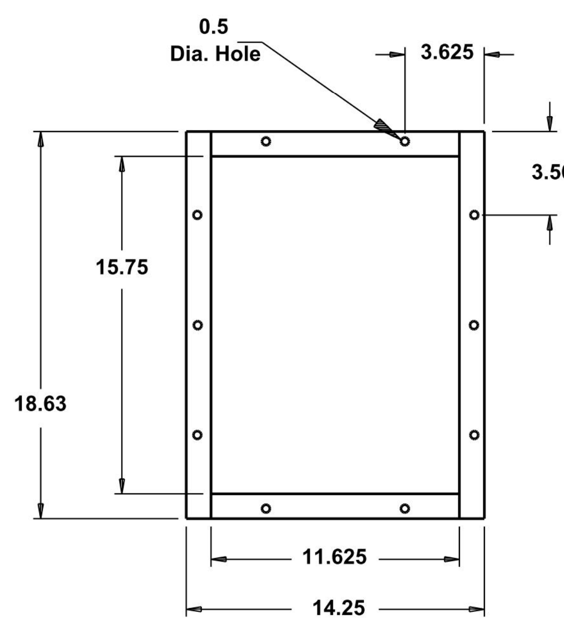
NOTES: All dimensions shown are in units of inches.
Drawings are not to scale. Drawings are of standard unit and do not include dimensions for accessories or design modifications.



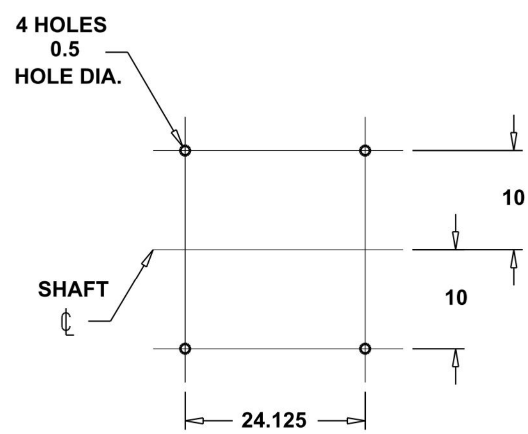
SIDE VIEW



END VIEW



OUTLET



FOOTPRINT